Implications of agronomic and environmental considerations in land application of manure in dairy farm systems of the Northeast and Mid-Atlantic Regions of the United States

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Introduction

To effectively address the problem of agricultural non-point source pollution, it is important to recognize that while individual farm nutrient management tactics are important, the root cause of the problem derives from the strategic organization of modern animal agriculture. Traditional dairy production in the northeast was characterized by relatively small, feed self-sufficient operations. In this context, there was a strong incentive to efficiently recycle manure nutrients to reduce the amount of fertilizer nutrients that had to be purchased to produce the crops that fed the dairy cows. Thus the potential for nutrient pollution was low and when there were problems they could often be addressed with tactical approaches utilizing mostly land-based "Best Management Practices" (BMPs). However, market based economics have increasingly produced an organizational pattern in modern dairy production whereby a significant proportion of feed for the dairy animals is not produced on the farm where the cows are located. This feed, mostly concentrates, may be produced on other land nearby but often it is produced on land long distances away (such as in the Midwest). This has resulted in a major accumulation of excess nutrients in the areas near where the animals are located (see e.g. Kellogg et al., 2000) with little economic incentive to redistribute the manure beyond that area. There is a significantly greater potential for nutrient loss to the environment from those areas of accumulation.

Consequently, significant non-market forces arising from environmental concerns are providing negative feedback about nutrient management resulting in a collision of economic and social power (Lanyon, 2000). However, many programs that attempt to address these concerns are based on the more traditional view of dairy farming outlined above and thus focus on tactical approaches almost exclusively utilizing land-based BMPs to address the problems. While this approach has improved manure nutrient management, the results have often fallen short of expectations because it does not recognize the real strategic issues facing many of today's dairy farmers. For instance, many nutrient management plans written to protect water quality by utilizing BMPs to maximize nutrient use efficiency in the on-farm cropping system can have significant negative economic consequences for the farm operation as a whole: The expense of hauling manure to more distant fields can easily exceed the nutrient value carried in the load! Therefore, to be effective, the tactical approaches used to address nutrient management issues must be considered in the context of this larger strategic picture. The BMP approaches are important and should reduce the immediate water quality impacts of intensive animal agriculture, but they do not address the larger nutrient imbalance/surplus that ultimately drives the water quality problem.

Environmental concerns led to public pressure which resulted in the development of rules for Concentrated Animal Feeding Operations (CAFO Rules) under the Clean Water Act. Similar efforts are under way in terms of air quality through the Air Quality Compliance Agreement for Animal Feeding Operations recently released by the Environmental Protection Agency (http://www.epa.gov/compliance). Several state and local programs and regulations are currently in place in the Northeast (NE) and Mid-Atlantic (MA) Regions to address these nutrient management issues.

Currently, under CAFO Rules, large animal feeding operations around the United States are developing and implementing comprehensive nutrient management plans (CNMPs). USDA programs are assisting some of the regulated large farms as well as non-regulated small farms to implement CNMPs, though more resources are always welcome. CNMPs need to be developed in accordance with USDA-NRCS standards and specifications. In a nutshell, a CNMP must implement BMPs to exclude clean water from animal production areas, collect and treat process wastewater and any water that has mixed with waste in the animal production areas, and collect and recycle manure nutrients on crop fields according to Land Grant guidelines. Many dairy operations have developed nutrient management plans and installed or applied a number of BMPs to address concerns identified in the farm plan development process.

CNMPs will continue to improve nutrient management on many farms and the implementation of CNMPs is a good first step. The industry deserves to be congratulated for continuing to make progress under difficult circumstances. However, in light of the changing strategic organization of modern dairy production, it must be asked whether our current agronomic and environmental guidelines are sufficient for acceptable nutrient retention in soils and crops. None of the BMPs currently in place effectively addresses the problem of nutrient imbalances. Is it possible that in an increasing number of situations, there just may be too many nutrients, even after unavoidable losses, to be satisfactorily recycled in practices applied through current BMP based CNMPs?

Dairy Farm Mass Nutrient Balance

Simply put, “Mass nutrient balance” (MNB) is the sum of the annual amount of N, P and K that enter a farm from various sources (imports) minus the annual amount of N, P and K that leaves the farm (exports). Typically, key dairy farm nutrient imports include nutrients in the form of feed, fertilizer, and, in the case of nitrogen, fixation of atmospheric N by legume crops as well as wet or dry deposition from the atmosphere. Exports can be in the form of milk, cattle sales, forage sold, leaching, denitrification, volatilization, runoff, and erosion. The list of imports and exports includes items that are more firmly under managerial control, such as milk production, cattle sales, and feed purchases. The list also includes items that are much more difficult to quantify and control, including N fixation by legumes, atmospheric deposition of N, leaching and runoff.

In a 1998 Cornell MS thesis, Bloomfield (1998) analyzed five NYS dairy farms representing five general categories: small conventional, large conventional, Amish, organic, and grazing. Taking into account nutrient imports through feed, fertilizer, purchased animals, bedding and N fixation and exports in the form of sales of milk, crops, and animals, four of the five farms had substantial annual nutrient surpluses, regardless of size. The fifth farm, an organic dairy, had a mass nutrient balance of nearly zero for P and a fairly low surplus for N; i.e. annual nutrient imports were approximately equal to annual nutrient exports. At the organic farm almost all feed was home grown and virtually no fertilizer was purchased; this farm was close to self-sufficient in both forage and feed concentrates, similar to the traditional NE dairy farm.

Are these results typical for the different farm types? With some exceptions, the majority of dairy farms in the Northeast (NE) and Mid-Atlantic (MA) produce forage requirements on existing cropland and purchase all or nearly all feed concentrate requirements from off-farm sources. Typically, about 50% of the ration on a dry matter basis is home-grown with the remainder being purchased from off-farm sources. Because of this, many NE and MA dairy farms have a substantial annual N, P and K surplus where imports far exceed nutrient exports. A study of 3 New York dairy farms (Klauser, 1993) found that 64-89% of the N, P and K imported annually on to the farm, could not be accounted for in exports of milk, cattle or feed. Additional studies are ongoing in New York but currently available data indicate that for roughly every 4 pounds of N, P or K that enters a dairy farm each year, only about 0.5 to 1.5 pounds are exported in product sales. Nutrient losses can occur in the barn, the feed storage and the manure storage but much of the remainder tends to be distributed on farm fields in the form of manure. Over time, that can result in soil fertility increases beyond optimum levels and/or losses to the environment. Nitrogen may accumulate somewhat in soil organic matter but significant amounts tend to cycle annually so that much of the N may be lost shortly after application and what is not used by crops during the growing season may be lost to the environment one way or another. Of the three major nutrients, N and P are water quality concerns, while N is also an air quality concern, so the balance of this paper will focus on these two nutrients.

Nutrients Excreted in Manure and Urine

The extent of surplus N and P on NE and MA dairy farms as shown by mass nutrient balance studies becomes more meaningful when examined in relation to the amount of nutrients that can actually be utilized by crops produced by operations in this circumstance.

There are many factors that impact nutrient excretion in manure and feces with diet and production level being key factors. In a set of as-yet unpublished data, Larry Chase, Cornell University, reports that in a sample of 41 NE dairy herds, the Cornell Net Carbohydrate and Protein System (Fox et al., 2003) predicts the range of total daily N excretion for milking cows to be about 0.8 pounds to 1.4 pounds (excluding the dry period). Production in these herds during the study period ranged from 54 to 118 pounds of milk per cow per day and ration crude protein ranged from 15.3 to 20.5%. At a milk production level of 80-85 pounds per cow, total N excretion is about 350 pounds per cow per year or very nearly 1 pound per cow per day. The model also suggests that (on average) replacements are estimated to excrete about one-half pound of total N per animal per day. These N excretion figures include organic-N in the feces and inorganic-N from the urine. Depending on the ration, approximately 55% of the excreted N is fecal N, and 45% is urinary N. The fecal-N is generally fairly stable and must be mineralized by microbes to become plant available N. The urinary-N is much more chemically active; it is excreted as urea and quickly converts to ammonia or ammonium-N when it mixes with feces on the barn floor.

For the same herd making 80-85 pounds of milk per cow per day, feeding a moderate P level of 0.42% P to lactating animals and 0.35% P to dry cows and heifers, the Cornell Net Carbohydrate and Protein System estimates the annual P excretion rate to be between 45-50 pounds per cow per year and 15-20 pounds per heifer per year. In fertilizer P equivalent (P_2O_5), each mature cow would then excrete about 100-110 pounds with replacements adding another 40 pounds of P_2O_5 per year.

If the example farm that averages 80-85 pounds of milk per cow per day supports one cow per acre (1.4 animal units per acre), there would thus be about 350 pounds of N and a little over 100 pounds of fertilizer P equivalent per year that "hits the barn floor". If the same farm supports one cow plus her replacement (2 animal units per acre), the annual amount of N that is excreted per acre is estimated at around 500 pounds and estimated P excretion in fertilizer equivalents would be 145 pounds of P_2O_5 per acre.

Carrying Capacity and Land Base Required for Forage Production

So what do we do with these nutrients? As indicated above, many NE and MA dairies utilize home-grown forage and purchase concentrates. This arrangement offers a key advantage in that the resulting land base required for crop production is reduced and therefore farm costs in terms of capital and management are decreased. In essence, it is forage productivity that determines the stocking rate of most dairy farms today.

Assume a "typical" dairy ration is: (1) 50% dry matter from forage and 50% dry matter from concentrates such as corn or soybean meal, etc.; (2) the forage dry matter fed is 50% from corn silage and 50% from hay or haylage; and (3) a moderately high producing cow will eat about 45 pounds per day of this ration on a dry matter basis over the course of 12 months. The ration requires the dairy producer to present about 8200 pounds of forage dry matter to the cow's mouth. Let's assume 10% of the dry matter is lost in the process of mixing/feeding and refusals. Also assume that 25% of the dry matter is lost between harvest and bunk silo storage under good management. The producer must harvest a little over 12,000 pounds, or 6 tons of forage dry matter, excluding safety margin for poor crop years. This compares well with the rule commonly used by producers: 6-7 tons of forage dry matter is needed per cow per year.

On good-very good soils a producer may average 22 tons per acre of corn silage at 35% dry matter. Hence, a 22 ton/acre crop of corn silage will supply about 7.7 tons of forage dry matter per acre. A very good alfalfa or grass hay crop will supply 4.5-5 tons of dry matter per acre. A dairy farm with half its acreage in corn silage and the other half in haylage with the yields above will have about 6 to 6.5 tons of forage dry matter to support the herd. As shown above, this level of productivity will support about one milking cow (1.4 animal units) per acre.

Some dairies have higher crop productivity, supporting a cow plus her replacement (about 2 animal units) from an acre of forage delivering 8-9 tons of forage dry matter per acre. Other dairies experience lower crop productivity; land resources, management and business philosophy are key factors. However, let's go with the fairly modest estimate of an acre of cropland will supply the necessary forage needs for one high-producing cow equaling 1.4 animal units per acre and that this results in a total excretion of about 350 lbs of total N and a little over 100 lbs of fertilizer P equivalent (P_2O_5) "per acre" in excreted nutrients.

Land Application and Crop Uptake

These calculations raise the question: "How many nutrients can this "average" harvest of about 6 to 6.5 tons of dry matter use?". The 2004 Dairy One forage analysis database for both New York and Pennsylvania samples (about 9,000 corn silage samples; http://www.dairyone.com/Forage/FeedComp/) shows an average P concentration of 0.23% P and an average crude protein concentration of 8%. For about 6,800 samples classified as "Mostly Mixed Legume (MML) silage" (we assume this represents mostly alfalfa/grass samples) average concentrations were 0.34% P and 18.5% crude protein. Based on these data, corn silage removes about 11 pounds of P_2O_5 and 26 pounds of N per ton of dry matter while alfalfa/grass stands remove about 15 pounds of P_2O_5 and 60 pounds of N per ton of dry matter.

Remember from above, our example is for a rotation that includes corn silage yielding 7-8 tons of dry matter and alfalfa/grass yielding 4.5-5 tons of dry matter per acre. Based on these assumptions, both crops remove about 75 pounds of P_2O_5 per acre with harvest. Crop N removal is estimated to be about 300 pounds per acre for the MML silage and 180 pounds per acre for the corn silage. For corn, the net N requirement must take into account expected contributions from other sources before considering N needed from manure. Soils of the NE and MA generally contribute at least 40 pounds of N per acre per year to crops. First year corn generally receives sufficient N from the plowed sod to meet crop needs that year and does not need additional N beyond a small starter N application that is recommended independent of cropping or manure history (assume 30 pounds of N applied with starter for the corn). Hence, over the 4 corn years in a 4 year alfalfa/grass and 4 year corn rotation, a net of about 110 pounds of N per acre is required. Factoring in a reasonable (in)efficiency factor (realizing that not all N applied is taken up by the crop), perhaps 160-170 pounds of N per acre per year (over the 4 year rotation) would be required to meet corn crop N needs. As for alfalfa, this crop does not "require" any additional N. However, the N-fixing bacteria and the legume itself will scavenge some N from manure when provided. Assuming 1/2 of alfalfa/grass N needs can be supplied from manure, about 150 pounds of N could be applied for this part of the rotation. Consequently, this example estimates that a 4 year corn and 4 year alfalfa/grass rotation could efficiently utilize an average of approximately 160 pounds N per acre per year.

Before we make comparisons with the amount of nutrients excreted by our cow, we should note that not every bit of nutrient excreted will be land applied and that it is impossible to use nutrients used in any biological system with 100% efficiency. Animal systems, including humans, can only use a fraction of the nutrients consumed. This is also true in dairy cattle who must extract much of their nutrient requirement from plant roughage, so current nutrient use efficiency for N and P runs around 25-40%. Similarly, because of weather patterns, soil conditions, and other factors, crops are unable to access 100% of the nutrients that are land applied, even in the best of circumstances. There are a number of loss pathways that each nutrient is prone to. Some losses can be relatively benign, while others are of environmental concern to us. For example, ammonia volatilization from the barn floor, storage surface and during land application of manure can result in significant losses of N. This reduces the actual amount of N available for land application. Further, some degree of denitrification can occur in many soils under certain conditions. Nitrate that gets denitrified escapes into the atmosphere in a gaseous form again reducing the amount of N available to the crop. Furthermore, not all N in manure is directly available for crop uptake. Also, depending on soil mineralogy, chemistry and hydrology, a significant portion of phosphorus can be stored in the soil. As the soil's capacity to store P is finite, the additional amount of P that a soil can store decreases with soil test P buildup over time while the potential for loss of P from the soil increases.

Taking the above into account, the comparison of excretion numbers described in our example with crop needs shows us <u>the degree of opportunity to improve nutrient utilization</u> in dairy farm systems. So, let's go back to our excretion calculations and compare these to crop needs.

In terms of P, we estimated that one cow excretes the equivalent of a little over 100 pounds of P_2O_5 and that our crop rotation needed about 75 pounds of P_2O_5 per acre per year over the rotation. This tells us that there is an annual surplus of about 25 pounds of P_2O_5 per acre. A recent summary of P balance in Pennsylvania, using a completely different approach estimated that there was an excess of 28 lb P_2O_5 per acre of cropland in the state, supporting the conclusion of this analysis. This surplus is useful when building toward optimum soil test P levels to maintain yields. However, the addition of fertilizer P as starter or top-dress along with manure application over time has resulted in a not-to-be neglected number of fields in the NE and MA regions reaching the point where there is little or no crop response to additional P. In Pennsylvania, for example, 52% of the soil tests for agronomic crops are in the above optimum range for P. In New York, 46% of the samples tested by the Cornell Nutrient Analysis Laboratory in 1995-2001 were high enough in P to eliminate the need for additional P or limit applications to no more than a small amount of starter P (Ketterings et al., 2005). Continuing to apply P to these fields at rates greater than crop removal can contribute to environmental losses through runoff and possibly leaching. Phosphorus losses may occur through erosion and runoff or through leaching to tile lines in certain conditions and these losses increase with greater P saturation of the soils.

In terms of N, we estimated that one cow excreted about 350 pounds of N and that our crop rotation needed about 160 pounds of N per acre. This gives us about 190 lbs of manure N on a per acre basis that cannot be accounted for in crop uptake if the annual manure production from one cow was applied to one acre. Depending on management, the original N pool of 350 pounds of N may be substantially reduced by urinary N losses through volatilization of ammonia from the barn floor and from storage. Substantial losses may also occur once manure is surface applied; most of the inorganic N will be lost to the air when manure is surface applied and not incorporated within a couple of days. Although we can currently balance N by accepting these air emissions, such management increases the rate of P accumulation and will not be sustainable in the long-term. Furthermore, we will be called upon to do a better job with reducing N losses to the air and odor emissions from farmsteads and farm fields. This will include substantially improving ammonia-N conservation which means lowering of manure rates per acre. This helps with our P accumulation issue but we need to look for additional changes on farms. One possibility for some farms is to substitute grass for alfalfa in the hay portion of the rotation, increasing N needs as grasses do not pull N from the air like legumes. Impacts of such decisions on whole farm nutrient balances and milk production need to be studied, as there are several practical reasons why many producers prefer alfalfa or alfalfa/grass in the rotation over grass alone.

The stocking density of one milking cow (1.4 animal units) per acre selected in our example is fairly modest when compared to some farms. As stocking density and/or reliance on imported feed increases, the gap between N and P excretion by cows and N and P needs of crops increases substantially. At 2 dairy animal units per acre (cow plus replacement) in a high producing herd, the N excretion is about 500 pounds and the P_2O_5 equivalent excretion is about 150 pounds per acre. We will need more than one acre to accept this manure if land application is the only way to deal with these nutrients.

Implications for Nutrient Management

In the past, concerns about the potential for nitrate leaching to the groundwater and to surface water determined application rates (N-based plans). More recently, phosphorus has received a great deal of attention. Basing nutrient management plans on a

P index is one example of an approach to P-based management. This approach targets efforts to minimize P loss to the environment but in a way that maximizes management flexibility. The P Index is a field evaluation tool that is based on the concept of Critical Source Area (CSA) management. Phosphorus loss generally occurs from only a small part of a watershed (CSAs) and only during a few storm events (Pionke et al., 1997). Within a watershed, CSAs can be found in areas where a concentrated source of P (manure, fertilizer, high soil tests) coincides with a mechanism to transport the P to water. The P Index combines readily available indicators of P sources (soil, fertilizer, manure) and P transport potential (erosion, runoff, leaching, connectivity to water) to provide an indication of the potential risk of P loss from agricultural fields. Thus, scientists studying P transport refer to “source” and “transport” variables as separate factors controlling P export from watersheds. The P Index concept has been widely adopted across the US (Sharpley et al., 2003). The field by field P Index assessment is used to determine whether the manure application rate may need to be limited and/or other management practices may be required to address P concerns. Other management practices may include installation of BMPs to reduce transport potential, such as common erosion control practices or buffers. Alternatively, changes in the time or method of manure application may reduce the risk of P loss to the point where manure can be applied.

The P Index is viewed as a practical, effective method of addressing P runoff related to manure applications because it focuses on critical factors found to impact P loss. The index identifies those fields that are likely to affect water quality by the loss of dissolved and sediment-bound P and limits application rates or directs implementation of other management practices, as the situation warrants. Phosphorus-based nutrient management plans generally result in greater restrictions in manure rates and application methods. However, even though the P Index has been shown to be an effective tool for targeting BMPs to reduce P loss to the environment, it does not get at the strategic issues at the root of the nutrient management problem and thus is only part of the solution.

A concern with nitrogen is the potential impact of ammonia volatilized from animal operations. A primary approach to reducing the potential for this loss is BMPs that conserve the ammonia N. While these BMPs can effectively reduce ammonia loss, they have important implications for farm nutrient balance and land application. Conserving ammonia N increases the amount of N that is available for land application. Considering the earlier analysis which indicated significant excess N on many dairy farms, solving the ammonia volatilization problems will increase the N balance problem. Likewise, practices such as manure incorporation that would be a necessary component of land application systems to minimize ammonia loss will increase the crop available N and thus reduce allowable manure application rates, again increasing the N balance problem. This can also add a significant economic cost to manure utilization.

Other issues that are becoming increasingly important considerations in land application include soil quality, soil conservation and odor. The latter has become a focal point for potential conflict between some farms and their communities. While these issues are not necessarily directly related to nutrient management, there are critical interactions between many of these issues and farm nutrient balance and land application of manure. For example, many practices that are used to reduce odor from manure, either from the barn (e.g. frequent scraping, storage) or from field application (e.g. immediate incorporation or injection), will result in conserving a larger proportion of the manure N thus often increasing the N excess on the farm. Another example is that manure incorporation to reduce ammonia loss or control odor, often has negative impacts on soil quality and can increase soil erosion. This issue raises challenging social questions such as what is the relative impact on the environment of ammonia versus sediment. We have the technical challenge of trying to develop BMPs to address these conflicts and further research is needed on topics such as injection techniques that can be used in no-till cropping systems. We must also realize that part of the strategic vision that will be necessary to successfully address these nutrient management related problems must include full consideration of community relations.

With increasing environmental pressures, we need to look for economically feasible management options that optimize nutrient use on the farm, reduce inputs and increase outputs thus improving nutrient balances and reducing losses to the environment. This includes development and evaluation of management options that optimize forage quality and animal diets and adjust crop rotations and stocking densities to soils, nutrient supply and needs (e.g. grass forage versus legume-based forages) and ration needs. Addressing air and water quality and P accumulation issues will require a reduction of manure application per acre in many situations. Although this does not necessarily have to lead to an increase in fertilizer costs, manure nutrients that cannot be used in land application may need to be harvested from the manure stream by some combination of treatment processes for export and use off-farm.

For example, at the present time substantial feed grain and forage self-sufficiency could require perhaps 50% more land than most dairies currently operate, and this assumes that a location is suitable for grain production to begin with. Because of constraints imposed by a combination of previous expansions, geography/climate, and land availability or affordability, and farm economics, self-sufficiency in terms of concentrates is currently not a viable option for many dairy farms in the NE and MA.

Conclusions

While land application will continue to be a critical component of nutrient management on dairy farms in the future, there are many varied factors that will impact the land application systems adopted on farms in our region. Our assessment of nutrient balances on NE and MA dairy farms illustrates the dilemma faced by many dairy producers. Any land application based approach on intensive dairies which use significant off-farm sources of feed must recognize that there will be fewer options for manure utilization on cropland over time. Most programs that address concerns with nutrient pollution from agriculture focus on crops and land application BMPs but it is clear from the previous discussion that the problem is only indirectly related to crop production and that it is really driven primarily by animal production. In other words, because of the nutrient imbalances inherent in these production systems, it is very unlikely that land application BMPs alone will be able to solve the current and future nutrient management problems.

From a strategic perspective land application systems must be developed and implemented within the context of the organization of modern dairy production systems.

For modern dairy farms in the NE and MA regions, whole farm nutrient balance will be the driving force for achieving water quality, and other environmental goals and integrated systems must be developed that not only use land application but also include import and export components. To make exporting manure nutrients economically feasible innovative systems will need to be developed to treat the manure to make it more economical to transport or to add value to the manure nutrients.

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